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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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PHYSICAL METALLURGY DIVISION

INTERNAL REPORT PM-R-69-5

THE EFFECTS OF COPPER AND MAGNESIUM ADDITIONS TO HYPEREUTECTIC ALUMINUM-SILICON ALLOYS PREPARED BY POWDER METALLURGY

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Nuclear and Powder Metallurgy Section

April 25, 1969

90-04656/

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SUMMARY OF RESULTS

Additions of 1% Cu, 2.5% Cu, 1% Mg and 2% Mg were made to Al-35% Si alloy melts, each of which was converted to powder by atomization. There was no significant effect on the sieve analysis, apparent density and flow rate of the powder. An increase in the hardness of hot-pressed and heat-treated specimens was observed. An increase in tensile properties was found in heat-treated specimens. Wear resistance was improved and the coefficient of thermal expansion was increased. Some porosity was evident after heat treating.

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INTRODUCTION

In previous work[1], it has been shown that hypereutectic aluminum-silicon alloys with up to 45% Si can be produced with a refined silicon phase by powder metallurgy techniques without the use of nucleation catalysts. Pre-alloyed powders were produced by atomization and the powders were consolidated by hot pressing.

The purpose of this investigation was to observe the effect of additions of copper and magnesium on the properties of the Al-35% Si alloy produced in the same manner.

EXPERIMENTAL PROCEDURE

Preparation of Alloy Powders

The materials used to prepare the experimental alloy powders are listed in Table 1, and the compositions of the powders are listed in Table 2.

Melting and alloying of 1400- to 1600-gram melts were carried out at 1050°C (1920°F) in zirconia-washed silicon-carbide crucibles heated in a resistance furnace. The melts were degassed with "Foseco" tablets* then skimmed and atomized.

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*A proprietary brand of degassing agent containing a chlorinated hydrocarbon.

After drying, the atomized powders were screened and the plus 100-mesh fraction was discarded. When more than one melt of an alloy was required, the minus 100-mesh fractions of the respective alloy powders were blended in a twin-shell laboratory blender.

Chemical Analysis

Samples for chemical analysis were taken from the minus 100-mesh powder.

Flow Rate, Apparent Density and Screen Analysis

The flow rates and apparent densities of the minus 100-mesh powders were determined in accordance with Metal Powders Industries Federation (MPIF) Standards 3-45 and 4-45, respectively. Screen analysis was determined in accordance with MPIF Standard 5-62.

Compacting and Hot Pressing

The alloy powders were cold pressed, isostatically, at 10,000 psi into 1 5/16-in. diameter by 2 7/8-in. long billets. Before hot pressing in a heated alloy-steel die having a 1 1/4-in. diameter bore, the compacts were ground to 1 3/16-in. diameter then wrapped in 0.005 in. stainless steel foil to prevent galling. All cold-pressed billets were heated in the hot die at temperature for 15 min then a load of 38,000 psi was applied for 5 min. The Al-35% Si alloy was hot pressed at the eutectic temperature, 577°C (1070°F) and also at 500°C (1020°F). The Al-35% Si-Cu alloys (eutectic temperature 540°C, 1005°F) were hot pressed at 510°C (950°F)

and 550°C (1020°F), and the Al-35% Si-Mg alloys (eutectic temperature 551°C, 1020°F) at 530°C (985°F) and 560°C (1040°F).

Heat Treatment

The effects of heat-treatment on the mechanical properties of the powder alloys were investigated. The 1 1/4-in. diameter hot-pressed billets were cut longitudinally into four quadrants, and those of the Al-35% Si and Al-35% Si-Cu alloys were heated to 520°C (970°F) for 6 hr then quenched into boiling water followed by ageing at 200°C (390°F) for times of up to 5 hr. The quadrants of the Al-35% Si-Mg alloy billets were heated at 535°C (1000°F) for 6 hr, quenched into boiling water then aged at 160°C (320°F) for 4 hr. All heat treatments were carried out in air in a muffle furnace.

Mechanical Testing

Vickers Hardness Numbers (VHN) were determined for all alloys in the hot-pressed and heat-treated conditions.

Room-temperature tensile tests were carried out on an Instron machine on all alloys in the as-hot-pressed condition, and on Al-35% Si-Cu and Al-35% Si-Mg alloys in the heat-treated condition. Tensile specimens, which were machined to PMD Drawing No. 44, were 1-in. long and had a gauge length of 0.622 in. and a gauge diameter of 0.178 in.

Thermal Expansion

The coefficient of thermal expansion between 20°C (70°F) and 300°C (570°F) was determined for each of the experimental alloys and also for an Al-11.5% Si casting alloy which was included for comparison purposes. The dilatometer specimens were 1.38-in. long by 0.130-in. diameter.

Metallography

For microexamination, hot-pressed and heat-treated specimens of each alloy were ground on silicon carbide paper to a 600 grit then polished with Linde A and Linde B compounds on microcloth.

Wear Testing

The wear properties of the alloys were assessed by determining the weight loss of a 1/8-in. diameter by 1/2-in. long pin of the material after the end of the pin had been in dry contact with a rotating cast-iron disc. The conditions of the test were 1000 psi and a speed of 200 in./min for 1 hr. For comparison purposes, in addition to the powder alloys, tests were carried out on a commercial casting alloy with a nominal silicon content of 11.5% and sodium-modified.

Density

Densities of hot-pressed and heat-treated specimens were determined according to ASTM Designation B311-58, based on water displacement.

RESULTS AND DISCUSSION

Alloy Composition

Chemical analysis results listed in Table 2 agree closely with the nominal compositions except for the Al-35% Si-2% Mg (nominal) powder in which the actual magnesium content was low (1.4%). The 0.2% Fe in all powders was from the aluminum-silicon hardener.

Properties of Powders

The sieve analyses for all the minus 100-mesh powders are listed in Table 3. These results show that the particle-size distribution in all powders was similar. Over 50% of each powder was in the minus 100-plus 200-mesh range. The remainder was distributed equally in the minus 200-mesh ranges except for the small percentage of plus 100-mesh material found in each powder.

The apparent densities and flow rates are given in Table 4. The copper and magnesium alloying additions had very little effect on these properties.

Properties of Compacts

Microexamination revealed a fine distribution of primary silicon in all the alloys. Figure 1 is a photomicrograph of the structure of the hot-pressed (530°C, 985°F) Al-35% Si-2% Mg alloy and is typical of the structure of the other hot-pressed alloys. It was noticed in some cases that the heat-treated alloys exhibited porosity that was not present in the

hot-pressed material. This can be seen by comparing the structure in Figure 1 with the structure of this alloy after heat treatment shown in Figure 2. This porosity could have been due to incipient fusion occurring during heat treatment. The solution heat-treatment temperature for the Al-35% Si-2% Mg alloy was only 16°C (60°F) below the eutectic temperature (535°C, (995°F) vs 551°C, (1020°F)) and it is possible that the presence of impurities in the alloy lowered the eutectic temperature a few degrees.

The effect of hot-pressing temperature and heat treatment on the hardness of the alloys is shown in Tables 5 and 6. The hardness of the Al-35% Si alloys was not influenced by the hot-pressing or the heat treatment. Additions of 1% Cu increased the hardness of hot-pressed specimens but heat treatment had little effect on this alloy. Addition of 2.5% Cu further increased the hardness of hot-pressed specimens, and after solution heat treating and then ageing for 1 hr, specimens that were hot-pressed at 550°C (1020°F) increased in hardness from VHN 138 to VHN 178.

The Al-Si-Mg alloys were given the heat treatment recommended for a commercial aluminum alloy containing silicon and magnesium. Results in Table 6 show that the heat-treated specimens were harder than those that were only hot pressed. This hardening was presumably due to precipitation of Mg_2Si from solid solution.

Heat-treated specimens of the Al-35% Si-2.5% Cu, Al-35% Si-1% Mg and Al-35% Si-2% Mg alloys that were hot pressed above their eutectic temperatures had higher hardnesses than those hot pressed below the eutectic temperature. The reason for this is not known.

Tensile-test results are shown in Table 7. Also included in Table 7 are values for specimens heat treated to give the hardnesses underlined in Tables 5 and 6. Of the specimens tested, those with the highest tensile strengths were: Al-35% Si-2.5% Cu hot pressed at 550°C (1020°F) and aged for 1 hr (30.2 kpsi), Al-35% Si-1% Mg hot pressed at 530°C (985°F) and aged for 4 hr (32.7 kpsi) and Al-35% Si-2% Mg hot pressed at 530°C (985°F) and aged for 4 hr (29.4 kpsi). All specimens exhibited low ductility which, however, is normal for hypereutectic aluminum-silicon alloys. The tensile strengths of the above heat-treated alloys showed improvement over that of Al-35% Si (24.9 kpsi).

The coefficients of thermal expansion for the alloys between 20°C (70°F) and 300°C (570°F) are listed in Table 8. The addition of copper or magnesium caused some increase in the coefficient of thermal expansion which, however, was still below that of an Al-11.5% Si casting alloy.

Wear test results in Table 9 show that the weight loss of 142 x 10^{-4} g for Al-35% Si powder alloy is considerably less than for an Al-11.5% Si cast alloy (173 x 10^{-4} g). The addition

of copper or magnesium further improved the wear resistance of the powder alloy.

Densities of hot-pressed and heat-treated specimens ranged from 2.48 to 2.59 g/cc. The different hot-pressing temperatures had no effect on the densities but a slight decrease in density was observed after heat treating. This decrease can be attributed to the porosity that developed during heat treatment.

CONCLUSIONS

1. Additions of copper or magnesium to an Al-35% Si powder alloy did not effect the sieve analysis, apparent density or flow rate of the atomized powder.
2. The primary silicon was finely divided in all experimental Al-35% Si powder alloys containing copper or magnesium.
3. Additions of 2.5% Cu, 1% Mg or 2% Mg to an Al-35% Si powder alloy increased the hardness of hot-pressed and heat-treated specimens.
4. Additions of 2.5% Cu, 1% Mg or 2% Mg to the Al-35% Si powder alloy increased the tensile strength of heat-treated specimens.
5. While the coefficient of thermal expansion of the Al-35% Si powder alloy was slightly increased by the addition of copper and magnesium it remained substantially lower than that of an Al-11.5% Si casting alloy.

6. Densities of the aluminum-silicon specimens containing copper and magnesium were not affected by the hot-pressing temperature but decreased on heat treating.

REFERENCE

1. H. M. Skelly and C. F. Dixon - "Hypereutectic Aluminum-Silicon Alloys Produced by Hot Compaction of Atomized Powder" - Mines Branch Research Report R 184, Department of Energy, Mines and Resources, Ottawa (1966).

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TABLE 1

Alloy Materials

Material	Purity	Source
Aluminum	99.99%	Aluminum Co. of Canada Ltd.
Aluminum-50% Silicon Hardener	48.5%Si,0.26%Fe	Kawecki Chemical Co.
Magnesium	99.9%	Dominion Magnesium Ltd.
Copper	O.F.H.C.	American Metals Climax Inc.

TABLE 2

Alloy Compositions

Nominal Composition	Chemical Composition			
	%Si	%Cu	%Mg	%Fe
Al-35%Si-1%Cu	35.3	1.0	-	0.2
Al-35%Si-2.5%Cu	34.6	2.5	-	0.2
Al-35%Si-1%Mg	35.3	-	0.9	0.2
Al-35%Si-2%Mg	36.0	-	1.4	0.2
Al-35%Si	34.0	-		0.2

TABLE 3

Sieve Analysis of Powders

U.S.Sieve No.	Weight, %				
	Al-35%Si	Al-35%Si-1%Cu	Al-35%Si-2.5%Cu	Al-35%Si-1%Mg	Al-35%Si-2%Mg
-80 + 100	2.2	2.0	2.2	3.2	1.6
-100 + 140	39.0	38.8	33.6	40.0	35.6
-140 + 200	19.8	20.6	20.6	20.2	20.4
-200 + 230	11.8	11.8	12.2	11.0	11.8
-230 + 325	13.4	13.2	14.2	12.2	14.0
-325	13.8	13.6	17.2	13.4	16.6

TABLE 4

Apparent Density and Flow Rate of Powders

Alloy	Apparent Density, g/cc	Flow Rate(sec/50 g)
Al-35%Si	0.96	110.8
Al-35%Si-1%Cu	0.90	118.3
Al-35%Si-2.5%Cu	0.93	107.7
Al-35%Si-1%Mg	0.89	111.4
Al-35%Si-2%Mg	0.90	111.9

TABLE 5

Hardness of Al-35%Si and Al-35%Si-Cu Alloys

Alloy	Hot Press Temp.	Hardness (VHN)						
		Hot Pressed	Sol. H.T. 520°C(970°F)6 hr	Aged 200°C(390°F)				
				1 hr	2 hr	3 hr	4 hr	5 hr
Al-35%Si	550°C(1020°F)	85	94	93	93	95	86	88
Al-35%Si	577°C(1070°F)	78	92	-	88	90	84	84
Al-35%Si-1%Cu	510°C(950°F)	128	123	124	120	126	115	117
Al-35%Si-1%Cu	550°C(1020°F)	123	125	124	131	131	124	119
Al-35%Si-2.5%Cu	510°C(950°F)	132	157	143	147	151	141	135
Al-35%Si-2.5%Cu	550°C(1020°F)	138	152	178	176	169	165	161

TABLE 6

Hardness of Al-35%Si-Mg Alloys

Alloy	Hot Press Temp.	Hardness (VHN)		
		Hot Pressed	Sol. H.T. 535°C(1000°F)6 hr	Sol. H.T. 535°C(1000°F) 6 hr Aged 160°C(320°F)4 hr
Al-35%Si-1%Mg	530°C(985°F)	95	130	156
Al-35%Si-1%Mg	560°C(1020°F)	94	142	164
Al-35%Si-2%Mg	530°C(985°F)	100	138	160
Al-35%Si-2%Mg	560°C(1020°F)	115	150	183

TABLE 7

Tensile Properties of Powder Alloys

Alloy	Hot Press Temp.	Condition	UTS (kpsi)	0.2% YS (kpsi)	% El $4\sqrt{\text{area}}$	VHN
Al-35%Si	550°C(1020°F)	Hot Pressed	24.9	23.4	3	85
Al-35%Si	577°C(1070°F)	Hot Pressed	23.6	22.7	2	78
Al-35%Si-1%Cu	510°C(950°F)	Hot Pressed	22.5	-	2.5	128
Al-35%Si-1%Cu	550°C(1020°F)	Hot Pressed	26.7	-	2.0	123
Al-35%Si-1%Cu	510°C(950°F)	Sol. H.T.	22.6	-	1	123
Al-35%Si-1%Cu	550°C(1020°F)	Aged 2 hr	24.8	-	2	131
Al-35%Si-2.5%Cu	510°C(950°F)	Hot Pressed	21.4	-	1.5	132
Al-35%Si-2.5%Cu	550°C(1020°F)	Hot Pressed	24.5	-	2.5	136
Al-35%Si-2.5%Cu	510°C(950°F)	Sol. H.T.	25.2	-	1	157
Al-35%Si-2.5%Cu	550°C(1020°F)	Aged 1 hr	30.2	-	1	178
Al-35%Si-1%Mg	530°C(985°F)	Hot Pressed	25.3	25.3	2.0	95
Al-35%Si-1%Mg	560°C(1020°F)	Hot Pressed	26.3	25.9	2.0	94
Al-35%Si-1%Mg	530°C(985°F)	Aged 4 hr	32.7	-	1.5	156
Al-35%Si-2%Mg	530°C(985°F)	Hot Pressed	26.8	25.8	1.5	100
Al-35%Si-2%Mg	560°C(1020°F)	Hot Pressed	22.2	-	2.0	115
Al-35%Si-2%Mg	530°C(985°F)	Aged 4 hr	29.4	-	2.0	161

TABLE 8

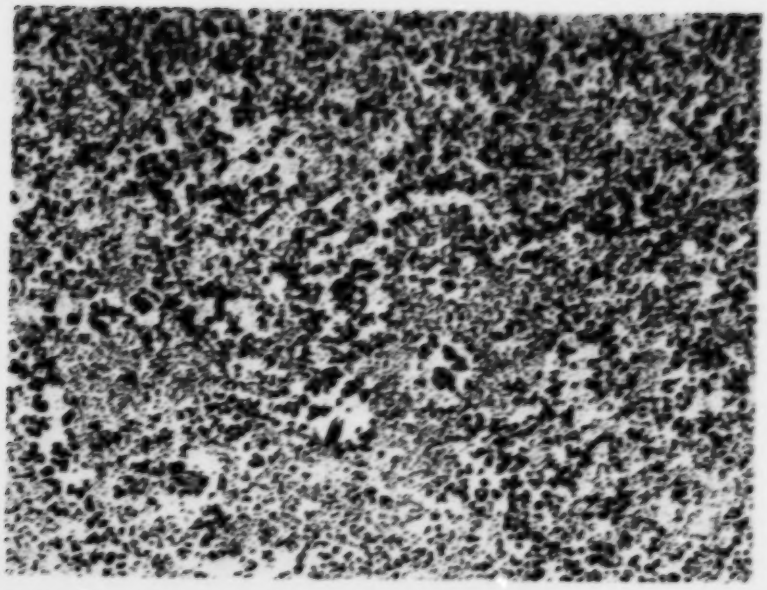
Thermal Expansion Coefficients of Powder Alloys

Alloy	Coefficient (in./in./°Cx10^6)	Temperature Range
Al-11.5%Si	21.50	20°C-300°C(70°C-570°F)
Al-35%Si	15.41	20°C-300°C(70°F-570°F)
Al-35%Si-1%Cu	16.23	20°C-300°C(70°F-570°F)
Al-35%Si-2.5%Cu	16.12	20°C-300°C(70°F-570°F)
Al-35%Si-1%Mg	16.40	20°C-300°C(70°F-570°F)
Al-35%Si-2%Mg	16.43	20°C-300°C(70°F-570°F)

TABLE 9

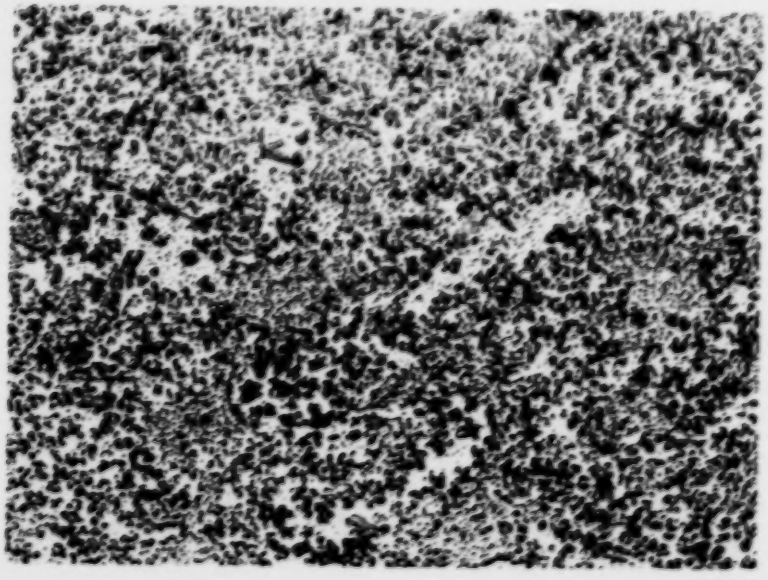
Wear Tests Results

Alloy	Condition	Weight Loss After 1hr($gx10^4$)
Al-11.5%Si(Casting Alloy)	As Cast	173
Al-35%Si	Hot Pressed 550°C(1020°F)	142
Al-35%Si-1%Cu	Hot Pressed 550°C(1020°F)Sol.Heat-Treated	102
Al-35%Si-2.5%Cu	Hot Pressed 550°C(1020°F)Sol.Heat-Treated	93
Al-35%Si-1%Mg	Hot Pressed 530°C(985°F) Aged 4 hr	104
Al-35%Si-2%Mg	Hot Pressed 530°C(985°F) Aged 4 hr	116



X100

Figure 1. Al-35%Si-2%Mg
Hot Pressed 530°C(985°F)
As Polished.



X100

Figure 2. Al-35%Si-2%Mg
Hot Pressed 530°C(985°F)
H.T. 535°C(1000°F) 6 hr
Quenched Into Boiling Water
Aged 160°C(320°F) 4 hr
As Polished.